6.0 HEALTH RISK ASSESSMENT

6.1 Introduction

Risk is the probability of injury or death. Risk assessment is a scientific procedure to determine the probability of adverse health effects from a specific exposure to a toxic agent. The chief goal of chemical risk assessment is to characterize the types of hazards associated with a substance and to estimate the probability that those hazards will be realized in exposed populations or individuals. Risk assessment depends upon data derived from experimental and epidemiological investigations into the hazardous properties of chemicals and from studies of the magnitude of human exposure to them. Risk assessment is a multi-stage process comprising the following tasks: (1) hazard assessment, (2) dose-response assessment, (3) exposure assessment and (4) risk assessment. Although these steps are presented sequentially, the process of risk assessment is highly iterative. The methods we have used in implementing the risk assessment process for Galveston Bay seafood closely follow the guidelines promulgated by the U.S. Environmental Protection Agency (U.S. EPA, 1989) for assessing human health risks from chemically contaminated fish and shellfish. Further guidance on the practical application of risk assessment was obtained from a similar analysis conducted for the Environmental Protection Agency on Puget Sound seafood (Tetra Tech, 1988). It should be noted that risk assessment is only an estimate of risk which depends upon the various assumptions detailed below.

6.1.1 Summary of Risk Assessment Process for Galveston Bay Seafood

The risk analysis of chemical contaminants in Galveston Bay fish and shellfish was organized into the following major sections:

- Collection of samples of fish, crabs and oysters with subsequent analysis of tissues for trace metals, polynuclear aromatic hydrocarbons (PAH), pesticides and polychlorinated biphenyls (PCB). Data used for risk assessment are on a wet weight basis.

- Examination of seafood consumption profiles and assessment of human health risks due to consumption of Galveston Bay fish and shellfish. Little real data were available, thus, estimates were used as described below.

- Presentation of the data in a graphical format for evaluating potential health risks throughout the bay.

During this GBNEP-funded study, multiple samples of several species of fish were collected and analyzed along with one species of crab and Virginia oyster. Fish species collected included: spotted seatrout, black drum, southern flounder, red drum, spanish mackerel, Atlantic croaker, spotted seatrout, and hardhead catfish. These fish were collected from four locations in Galveston Bay: Morgans Point (GBMP), Eagle Point (GBEP), Carancahua Reef (GBCR) and Hanna Reef (GBHR). These locations were chosen because they are in different regions of the bay and thus provide a broad view of bay seafood. The chemical data were then evaluated in a health risk assessment that followed the multi-step process outlined above. In the hazard assessment, all chemicals measured in the samples (trace metals, pesticides, polychlorinated biphenyls and aromatic hydrocarbons) were evaluated in a preliminary risk assessment. Dioxin was not included in the risk assessment because it was not measured during this study. All of the trace metals measured were considered significant and included in the assessment. Many of the organic chemical compounds were found only in very low concentrations. These very low analytes were not considered individually in our assessment. However, in order to not neglect the possible importance of these low-level compounds, we grouped the major organic compounds and considered the groups for the purpose of the health risk assessment. Individual compounds and groups of compounds that we used in this risk analysis are shown in Table 6.1. The individual compounds used in this assessment are most of the same chemicals considered in a similar assessment made for Puget Sound (Tetra Tech, 1988). In the final analysis, 11 individual chemicals and 5 compound groups of concern were selected for detailed evaluation of risks. In the dose-response assessment, dose-response variables for the 16 candidate individual chemicals or groups were obtained. The exposure assessment consisted of an evaluation of the concentrations of contaminant chemicals in the tissue of the fish, crabs and oysters at the four sampling locations in Galveston Bay. This evaluation also included an examination of seafood consumption rates that was based in part on estimates of commercial seafood landings in Galveston Bay (Quast *et al.*, 1989) and recent surveys of catch and consumption patterns by recreational fishermen (Ditton *et al.* 1990; Osburn *et al.*, 1988). In the risk assessment, the dose-response information and consumption rate information are combined to quantitatively estimate the range of health risks associated with consumption of fish, crabs and oysters with the chemicals of concern.

6.2 Risk Determination

6.2.1 Hazard Assessment and Selection of Chemicals of Concern

Hazard identification and evaluation involves review and evaluation of various types of experimental and epidemiological information for the purposes of identifying the nature of the hazards associated with a substance. The types of compounds of concern are well known and are included on the EPA list of priority pollutants. Priority pollutants were analyzed during this study to ascertain which chemical contaminants were present in Galveston Bay seafood to merit attention during the risk assessment process. The analytical results for the chemicals of concern have been presented in the previous sections. While dioxin is obviously a chemical of concern, it was the subject of a previous study (Crocker and Young, 1990) and was not measured as part of our study.

Of the analytes (trace metals and hydrocarbons) measured during this study, candidate chemicals or compound groups were evaluated according to the the risk assessment guidelines established by the U. S. Environmental Protection Agency (1989). Our sampling for this evaluation provided chemical contaminant data for fish, crabs and oysters from four locations in Galveston Bay (Figure 3.1). The crabs and oysters were all of the same species, while the kinds of fish sampled varied considerably among areas. The inter-species differences in fish contaminants in each particular region of the bay were small compared to variability in many of the assumptions associated with the risk assessment process. Thus, for the purposes of this risk assessment, the fish data were not considered individually by species. The risk assessment was undertaken individually for three seafood categories (fish, crabs and oysters) at each of the four locations sampled. In addition, an overall average risk was determined for Galveston Bay by combining the chemical data from all four locations and performing the risk assessment as described below.

6.2.2 Dose-Response Assessment

Dose-response evaluation involves identifying the observed quantitative relationships between exposure and risk and extrapolating from the conditions for which data exist to other conditions of interest. One of the difficulties in the dose-response evaluation process is that there is detailed information on only a few compounds in the various categories, especially for aromatic hydrocarbons and pesticides. Adequate data for assessing risk does not exist for all of the individual components and the data available for estimating the risk is often much better for some components than others. Considering these limitations, there are several possible approaches that can be followed to estimate the potency factor or reference dose value for compounds whose potency is unknown. In many studies compounds with unknown potency factors are simply ignored. We feel that this is not a good approach as compounds that are in high concentration and may be of concern are ignored because no potency factor is available. Another method that is under development by EPA is the equivalency approach, which takes data available for one analyte and applies it to other analytes using a weighting factor. When this approach is fully developed, it will be a superior approach.

The dose-response approach we use in our health risk assessment of Galveston Bay seafood is the group equivalent approach. In this approach, it is assumed that chemicals in a group with unknown potency factors have the same potency factor as the well-described members of the group. The risk calculated by this procedure is only an estimate, but it is invariably more reasonable than estimates obtained by ignoring all but a few well-described contaminants as was done for Puget Sound (Tetra Tech, 1988)

The dose-response information for chemicals detected in fish, crabs and oysters from Galveston Bay is presented in Table 6.2. Human health risk characterization is conducted separately for carcinogens and non-carcinogens. The potency factors for carcinogens and reference dose information for non-carcinogens are based on the "Toxic Substances Spreadsheet" of the U.S. EPA Region 4. We used the dose response values in Table 6.2 for each of the metals. Combined group values were used for carcinogenic chemical groups shown in Table 6.1. The dose response values we used were 11.50 for PAH, 11.12 for benzene hexachloride (BHC), 7.7 for total PCB, 0.34 for total DDT, and 16.0 for dieldrin.

6.2.3 Exposure Assessment

Exposure assessment is the process of characterizing the human population exposed to the chemicals of concern, the environmental transport and fate pathways of those chemicals, and the frequency, magnitude and duration of the exposure dose (U.S. EPA, 1989). Exposure assessment requires knowledge of the concentration of the chemicals of concern (based on analysis performed as part of this study) and the amount of seafood consumed by individuals. The consumption estimation step is inherently the most difficult part of the risk assessment process and the part with the most uncertainty. There is no simple means of identifying the average consumer of Galveston Bay seafood. Yet, estimates of seafood consumption for fish, crabs and oysters can be made based on catch and consumption patterns of recreational fishermen and may also be determined from the levels of commercial landings.

The exposure assessment for consumption of chemically contaminated seafood from Galveston Bay was performed in several parts. The concentration of the chemicals of concern in Galveston Bay fish and shellfish were measured and compared with available U.S. Food and Drug Administration (FDA) tolerance or action levels. Second, seafood consumption rates were estimated based in part on the commercial landing rates and in part on recent surveys of recreational harvesters in Galveston Bay. Finally, chemical concentration data and consumption rates were combined to estimate the average daily dose associated with each of the chemicals or groups of chemicals of concern. Because the consumption rate information described was based on averages for all species within a category, dose estimates were derived only for the three major categories of seafood collected (fish, oysters and crabs).

Samples of the three seafood groups were collected at four locations. For purposes of the risk assessment, the individual sample data were converted to concentrations in wet weight (mg chemical per kg body weight) and the concentration of each contaminant for each location were averaged for each seafood group. These average contaminant levels at each location were then used along with seafood consumption rates to estimate the dose for each of the seafood groups.

Sea food consumption rates for Galveston Bay seafood were evaluated using recent reports of commercial fish landings (Quast *et al.*, 1989) and recreational harvesting from the bay (Ditton *et al.*, 1990). Commercial fisheries data for Texas has been compiled through 1988. Galveston Bay landings account for 32% of the total bay system commercial landings of seafood in Texas. Based on a compilation of recent data by the Texas A&M University Sea Grant Program (Haby *et al.* 1989), 68% of the total Texas landings of oysters (by weight) come from Galveston Bay, along with 23% of crab landings and 15.3% of the finfish landings. Galveston Bay also accounts for 3.5% of Texas shrimp landings, but shrimp were not included in the risk analysis conducted as part of this study.

The average U.S. seafood consumption for all categories of seafood (shrimp, oysters, crabs and finfish) is about 15 pounds per person per year. Since shrimp accounts for 16% of the seafood consumed (up from 11% in 1978, Haby *et al.* 1990), the average for the three seafood groups we considered is 11 pounds per year. While national averages are well known, few regional studies have been done which allow consumption rates to be measured in any exact way. One study done for Puget Sound estimated average consumption rates of 12.3 g/d for fish and 1.1 g/d for shellfish. In the absence of verifiable local estimates, EPA chose to use a total consumption rate of 6.5 g/day (e.g. Crocker and Young, 1990) for their dioxin study, which included Galveston Bay. This consumption number is extremely low compared to estimates being used in state water quality standards. When states have promulgated a consumption rate into their human health water quality standards, a much higher value is used. For example, Louisiana has promulgated human health water quality standards which incorporate a consumption rate of 20 g/day. While the State of Texas has not yet designated a standard average seafood consumption rate, an overall consumption rate of 15.0 g/d for marine seafood has been incorporated in the State of Texas revised water quality standards. We have chosen to use that total rate.

The seafood consumption rates that we used in this risk assessment are given in Table 6.3 The 15.0 g/d total seafood consumption rate was partitioned into categories for fish (12.3 g/d), oysters (1.6 g/d) and crabs (1.1 g/day). Our basis for this division was partly based on the Puget Sound study (Tetra Tech, 1988) and partly on Texas seafood statistics (Quast et al. 1989). Tetra Tech (1988) determined that the average Puget Sound seafood consumer ate 12.3 g/d finfish and 1.1 g/d shellfish. This total (13.4 g/d) is below the State of Texas average. We assume that part of the difference is the increased oyster consumption in Texas. Texas bays' oyster harvest accounts for over 3% of the total seafood commercially harvested in Texas each year. The meat weight of oysters landed in Galveston Bay in 1988 was 1,452,365 lbs. In 1990, the entire U.S. harvest of Eastern oysters (*Crassostrea virginica*) was 18,395,000 lbs. (Current Fisheries Statistics, 1991). Thus, the annual oyster harvest from Galveston Bay represents about 13% of the total U.S. harvest. Using this information, we assigned a consumption rate of 1.6 g/d to Galveston Bay oysters. This value is only a rough estimate, but our total average consumption does equal the 15.0 g/d that the State of Texas will be using for future water quality studies.

Besides estimating a risk for the average seafood consumer, risk assessment procedures also require calculation of risk at high consumption rates. In addition to the average consumer of Galveston Bay seafood, who eats an average of 12.3 g finfish, 1.1 g crabs and 1.6 g oysters per day, we also considered the seafood consumer who has an extremely high consumption rate of seafood. This person might be a recreational fisherman or a subsistence fisherman. The higher rate would apply to the 95th percentile of the fishing population. That is, only five percent of the seafood consumers would be expected to ingest seafood at the higher rates. Like the average rate, the seafood consumption rate for subsistence consumers is difficult to estimate since no definitive studies have been conducted for Galveston Bay. We originally used the same vales for Galveston Bay that Tetra Tech (1988) used for Puget Sound. Since these values (94.5 g/d for fish, 12.3 g/d for oysters and 12.3 g/d for crabs) were criticized as too low, we took a different approach to estimate the high consumption rate.

The EPA Tolerance Assessment System (TAS) estimate of meat consumption values is:

a.	Red Meat	134 g/d
b.	Poultry	30.4 g/d
c.	Fish	15.2 g/d

which yields a total meat consumption of 179.6 g/day. If a person ate only fish, he would consume about 180 g/d of fish. This would be the 99th percentile consumer. The 95th percentile consumer would consume less fish and our liberal estimate of the 95th percentile consumer is 147.3 g/d of seafood of all types. This is probably a high estimate since the 95th percentile consumer is estimated to consume 82% of the seafood consumed by the 99th percentile consumer. Based on 1982 survey data (obtained from Environ 1985), the 95th percentile consumer eats only 60% of the fish eaten by the 99th percentile consumer. However, we use a higher percentage to avoid criticism that our risk estimates are too low because our high consumption estimates are too low.

The problem now remains of how to partition the consumption among fish, crabs and oysters. The consumption breakdown that we use here for the subsistence seafood consumer is:

a.	fish	94.5 g/d
b.	crabs	21.5 g/d
c.	oysters	31.3 g/d
d.	TOTAL	147.3 g/d

Our basis for this division is designed to use the same high consumption rate for Galveston Bay fish as Tetra Tech (1988) used for Puget Sound fish consumption (94.5 g/d). The non-fish consumption (i.e. crab and oyster) is partitioned in the same ratios as for the average consumer: 41% for crabs; 59% for oysters. The average and high consumption estimates that we have made are not ideal, but based on available data we feel that they are both acceptable for Galveston Bay and are in line with levels from other estuaries. The average seafood consumption level we use, 15.0 g/d, is certainly more acceptable than the 6.5 g/d that Crocker and Young (1990) used for the dioxin risk assessment of Galveston Bay. Their average calculated risk would have been 2.3 times higher if they had used our values.

The level of exposure was calculated using EPA guidelines and is based on estimates of the chemical dose expressed as the amount of a given chemical ingested per unit of body weight per day (mg of a chemical per kg body weight per day). Dose estimates were calculated using the following expression:

$$D_{ij} = (C_{ij} \times I_j \times A_i)/B \qquad (6\text{-}1)$$

where:

D_{ij} = Dose of chemical i in seafood category j (mg/kg bdy wt/day)
C_{ij} = Conc. of chemical i in seafood category j (mg/kg seafood)
I_j = Ingestion rate for seafood category j (kg seafood/day)
A_i = Adsorption coefficient for chemical i (unitless)
B = Standard assumption for average lifetime body wt (70 kg).

Major assumptions in using this equation for dose estimation are that:

- Exposure occurs daily over a 70 year lifetime.
- A representative body weight for a lifetime of exposure is 70 kilograms.
- The adsorption coefficient is one (1) percent for ingested arsenic and 100 percent for the other chemicals.

The rationale for using a 1% adsorption coefficient for arsenic is that arsenic in seafood occurs primarily as complex methylated or organic chemical species, which are less toxic and more readily excreted than inorganic arsenic. The report on Puget Sound prepared for EPA by Tetra Tech (1988) cited several studies which led to the conclusion that only 1% of the concentration of total arsenic should be used to estimate risks associated with seafood consumption. We have made the same assumption.

6.2.4 Risk Assessment

The final risk assessment calculation involves combining the information on dose-response with that on exposure to derive estimates of the probability that the hazards associated with the substance will be realized under the conditions of the exposure experienced by the population group of interest.

Hazards associated with ingestion of non-carcinogens (primarily trace metals) in various seafood categories were expressed as a ratio:

$$RI_{ij} = D_{ij}/RfD_i \qquad (6\text{-}2)$$

where:

RI_{ij} = Risk index for chemical i in seafood category j
D_{ij} = Dose of chemical i in seafood category j (mg/kg/day)
RfD_i = Reference dose for chemical i (mg/kg/day).

This equation was used to calculate the risk index for each of the seafood categories for Galveston Bay. The chemicals of concern used in the calculation of non-carcinogenic risk index values were cadmium, chromium, copper, mercury, nickel, lead, selenium, silver and zinc.

Using equations 6-1 and 6-2, the risk index values in Table 6.2 and the average consumption rates in Table 6.3, a non-carcinogenic risk index value was calculated for each seafood category for each of the four sampling locations. The risk index values are presented in Table 6.4 and shown graphically in Figure 6.1. There are no significant differences between any of the locations for fish, oysters or crabs. Consumption of an average amount of fish and oysters results in about the same risk, while the risk from crabs is much lower. While the level of chemical contaminants in oysters is higher than fish, the average lifetime risk is about the same because the assumptions of the amount consumed is significantly different: 12.3 g per day for fish and 1.1 g per day for oysters.

Potential risks associated with each carcinogen of concern in various categories of seafood were estimated as the probability of excess cancer using the equation:

$$R_{ij} = 1 - \exp(-P_i \times D_{ij}) \qquad (6\text{-}3)$$

where:

R_{ij} = Risk associated with chemical i in seafood category j
P_i = Carcinogenic potency factor for chemical i (mg/kg/day)
D_{ij} = Dose of chemical in seafood category j (mg/kg/day).

The chemical groups used in the calculation were arsenic, PAHs, BHC, total chlordane, dieldrin, total DDTs and total PCBs.

Using equations 6-1 and 6-3, the carcinogenic risk numbers in Table 6.2 and the average consumption rates in Table 6.3, a carcinogenic risk value was calculated for each seafood category for each of the four sampling locations. The carcinogenic risk values are presented in Table 6.5 and shown graphically in Figure 6.2. There was a significant difference between locations for the carcinogenic risk values. The risk from oysters at the Morgans Point sampling site and for fish at Morgans Point and Eagle Point are higher than the risk from consuming oysters or fish from the other locations. The higher risks, which come primarily from elevated levels of PCBs and PAH, are higher in the upper parts of the bay where effects of increased inputs from the ship channel and the Trinity River would be expected. Estimated risks for persons who consume seafood at a high rate (Table 6.3) are shown for non-carcinogens in Table 6.6 and for carcinogens in Table 6.7.

The previous discussions considered carcinogenic and non-carcinogenic risk separately for each seafood group. In the final step of this risk assessment, the potential cumulative health risk associated with exposure to multiple carcinogenic chemicals or multiple non-carcinogenic chemicals in the Galveston Bay fish, oysters and crabs was determined by summing the risks for individual contaminants within each group and then summing the risk across all seafood categories at each location. Cumulative risks for non carcinogens were calculated using:

$$\text{Cumulative Non-carcinogenic Risk Index} = \sum \sum RI_{ij} \qquad (6\text{-}4)$$

where:

R_{ij} = Risk index for chemical i in seafood category j as calculated from equation 6-2.

Cumulative risk for carcinogenic chemicals were calculated using:

$$\text{Cumulative Carcinogenic Risk} = \sum \sum R_{ij} \qquad (6\text{-}5)$$

where:

R_{ij} = Probability of excess cancer risk due to chemical i in seafood category j as calculated from equation 6-3.

The non-carcinogenic risk index values and carcinogenic risk values for fish, oysters and crabs for both average and high consumption rates (see Table 6.3) are given along with the cumulative risk determined for each category in Table 6.8 for Hanna Reef, in Table 6.9 for Morgans Point, in Table 6.10 for Eagle Point, and in Table 6.11 for Carancahua Reef. As part of a dioxin tissue study conducted by EPA Region 6 (Crocker and Young, 1990), a risk level of 1×10^{-4} was used as a benchmarker and tissue risk values in excess of that level were flagged as a possible problem. EPA Headquarters is also adopting this approach to assess carcinogens in the National Bioaccumulation Study soon to be published. Galveston Bay values above this benchmark level are noted in our tables.

6.3 Comparison with Other Risks

Our health risk assessment of Galveston Bay seafood has included only those chemicals of concern that were measured in our analyses. Other chemicals of possible concern were not included but may be important. These chemicals of potential concern include tetrachlorodibenzo-p-dioxins and -dibenzofurans. Crocker and Young's (1990) study of these compounds at sites in Arkansas, Louisiana and Texas found high concentrations at two sites in Galveston Bay. They estimated a risk level for 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) of 2.14×10^{-4} for sea catfish at Morgans Point, 0.46×10^{-4} for blue catfish at San Jacinto Monument, 0.88×10^{-4} for oysters at Morgans Point and 7.93×10^{-4} for blue crabs at San Jacinto Monument. As part of this dioxin tissue study conducted by EPA Region 6, a risk level of 1×10^{-4} was used as a benchmark, and tissue risk levels in excess of that level were flagged as possible problems. Some of the risk levels found in Crocker and Young (1990) for Galveston Bay exceeded this benchmark level.

In evaluating our high consumption risk assessment estimates, we found the cumulative risk values for fish at Hanna Reef (3.1×10^{-4}), at Morgans Point (1.1×10^{-3}) and at Eagle Point (8.2×10^{-4}) to exceed the benchmark risk level which was used by EPA in Crocker and Young (1990) and which EPA used to flag risk levels as possible problems. The consumer of Galveston Bay seafood should also consider that the additional risk from 2,3,7,8-TCDD reported by Crocker and

Young (1990) would have to be added to our risk levels to obtain a total cumulative risk for our chemicals of concern plus 2,3,7,8-TCDD. It is difficult to simply add the values because this EPA dioxin study used a value of 6.5 g/d for a seafood consumption rate. Also, none of our risk estimates for crabs (for the average consumer) from any part of the bay were higher than 0.65×10^{-5}, while the highest 2,3,7,8-TCDD risk Crocker and Young (1990) found was in crabs. Our Morgans Point oyster risk estimates were below the EPA concern level, but the risk estimates for fish tissue were above the 1.0×10^{-4} benchmark that the EPA uses as the level where some action should be considered by the State. The person who consumes large quantities of seafood (based on our consumption assumptions) would exceed this EPA benchmark at all sites we examined in Galveston Bay.

Table 6.1 Categories of Candidate Chemicals or Compound Groups Based on Preliminary Risk Estimates

Priority	Toxic Class	Chemical or Compound Group
High	Carcinogens	Arsenic Polycyclic Aromatic Hydrocarbons (PAH); *including* anthracene thioanthene pyrene benzo(a)pyrene benzo(b)fluoranthene chrysene benzo(k)fluoranthene Polychlorinated Biphenyls (PCB); total PCB DDT and derivatives (DDD and DDE)
	Noncarcinogens	Cadmium, Lead, Phenanthrene
Medium	Carcinogens	Benzene hexachloride (BHC) Chlordane Dieldrin
	Noncarcinogens	Mercury, Copper
Low	Carcinogens	
	Noncarcinogens	Antimony, Chromium, Nickel, Selenium, Silver, Zinc

Table 6.2 Dose-response for chemicals detected in Galveston Bay fish, crabs and oysters

Chemical Class	Chemical	Carcinogens: Potency Factor (mg/kg/day)$^{-1}$	Carcinogens: Weight of Evidence[a]	Noncarcinogens: RfD (mg/kg/day)	Noncarcinogens: Confidence[b]
Metals	Antimony			0.0004	1
	Arsenic	1.500[c]	A		
	Cadmium			0.0030	
	Chromium (VI)			0.0050	1
	Copper			0.0370	
	Lead			0.0014	
	Mercury (methyl)			0.0003	2
	Nickel			0.0200	2
	Selenium			0.0030	
	Silver			0.0030	
	Zinc			0.2100	
LPAH	Anthracene			0.3000	
	Phenanthrene		D	0.0300	
HPAH	Benzo(a)anthracene	11.500	B2		
	Benzo(a)pyrene	11.500	B2		
	Benzo(b)fluoranthene	11.500	B2		
	Benzo(k)fluoranthene		D		
	Chrysene	11.500	B2		
	Fluoranthene			0.0400	
	Pyrene			0.0300	
PCBs	PCBs-total	7.700	B2		
Pesticides	alpha-BHC	6.300	B2		
	DDT-total	0.340	B2		
	DDD, 4,4'	0.240	B2		
	DDE, 4,4'	0.340	B2		
	DDT, 4,4'	0.340	B2		2
	Dieldrin	16.000	B2		1

[a] Weight of evidence ratings are (A) human carcinogen, (B1) probably human carcinogen based on limited epidemiological evidence, (B2) probable human carcinogen based on evidence from animal studies, (C) possible human carcinogen, (D) not classifiable as to human carcinogenicity, (E) evidence of noncarcinogenicity in humans.

[b] Confidence ratings are low (1), medium (2), and high (3).

[c] Potency factor based on interim recommendation of the U.S. EPA Risk Assessment Forum.

Table 6.3 Estimated average and high (95th percentile) consumption rates for fish, crabs and oysters used in risk assessment calculations.

Seafood Category	Average Value	High Exposure Value
Fish	12.3 g/day	94.5 g/day
Oysters	1.6 g/day	31.3 g/day
Crabs	1.1 g/day	21.5 g/day
Total Seafood Consumption	**15.0 g/day**	**147.3 g/day**

Table 6.6. Non-carcinogenic risk index values for Galveston Bay Seafood from four different areas of the bay. A high consumption rate is assumed.

Site	Fish	Oysters	Crabs
Hanna Reef	0.79	1.95	0.21
Morgans Point	0.84	2.76	0.30
Eagle Point	0.82	2.35	0.24
Carancahua Reef	0.77	3.31	0.50

Table 6.7. Carcinogenic risk values for Galveston Bay seafood from four different areas of the bay. A high consumption rate is assumed.

	Fish	Oysters	Crabs
Hanna Reef	3.1×10^{-4}	1.9×10^{-4}	7.0×10^{-5}
Morgans Point	1.1×10^{-3}	1.1×10^{-3}	9.6×10^{-5}
Eagle Point	8.2×10^{-4}	2.5×10^{-4}	5.3×10^{-5}
Carancahua Reef	3.3×10^{-4}	4.8×10^{-4}	1.3×10^{-4}

Table 6.8. Risk characterization for the chemicals of concern measured in this study at Hanna Reef in Galveston Bay.

	Non-Carcinogenic Risk Index Values**		Carcinogenic Risk Values***	
Seafood Category*	Average Consumption	High Consumption	Average Consumption	High Consumption
Fish	0.10	0.79	4.1×10^{-5}	3.1×10^{-4}
Oysters	0.10	1.95	9.5×10^{-6}	1.9×10^{-4}
Crabs	0.01	0.21	3.6×10^{-6}	7.0×10^{-5}
Cumulative Risk******	**0.21**	**2.95**	**5.4×10^{-5}**	**5.7×10^{-4}‡**

* Multiple chemical exposures via single category of seafood. Explanation of average and high consumption rate consumptions is given in text.

** All trace metals except arsenic were evaluated.

*** Carcinogenic chemicals evaluated were arsenic, PAHs, BHC, chlordane, dieldrin, DDT and its derivatives, and total PCBs.

**** Multiple chemical exposure via multiple categories of seafood for the chemicals measured in this study. Any risk from tetrachlorodibenzo-p-dioxins should be added to these values to give a total cumulative risk.

‡ As part of a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990) a risk level of 1×10^{-4} was used as a benchmark and tissue risk values in excess of that level were flagged as possible problems.

Table 6.9. Risk characterization for the chemicals of concern measured in this study at Morgans Point in Galveston Bay.

	Non-Carcinogenic Risk Index Values**		Carcinogenic Risk Values***	
Seafood Category*	Average Consumption	High Consumption	Average Consumption	High Consumption
Fish	0.11	0.84	1.4×10^{-4}	1.1×10^{-3}
Oysters	0.14	2.76	5.5×10^{-5}	1.1×10^{-3}
Crabs	0.02	0.30	4.9×10^{-6}	9.6×10^{-5}
Cumulative Risk****	**0.27**	**3.90**	**2.0×10^{-5}**	**2.3×10^{-3}‡¤**

* Multiple chemical exposures via single category of seafood. Explanation of average and high consumption rate consumptions is given in text.

** All trace metals except arsenic were evaluated.

*** Carcinogenic chemicals evaluated were arsenic, PAHs, BHC, chlordane, dieldrin, DDT and its derivatives, and total PCBs.

**** Multiple chemical exposure via multiple categories of seafood for the chemicals measured in this study. Any risk from tetrachlorodibenzo-p-dioxins should be added to these values to give a total cumulative risk.

‡ As part of a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990) a risk level of 1×10^{-4} was used as a benchmark and tissue risk values in excess of that level were flagged as possible problems.

¤ In a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990), EPA Region 6 recommended that if the 1×10^{-3} criterion was exceeded the State should consider issuing a fishing consumption ban.

Table 6.10. Risk characterization for the chemicals of concern measured in this study at Eagle Point in Galveston Bay.

	Non-Carcinogenic Risk Index Values**		Carcinogenic Risk Values***	
Seafood Category*	Average Consumption	High Consumption	Average Consumption	High Consumption
Fish	0.11	0.82	1.1×10^{-4}	8.2×10^{-4}
Oysters	0.12	2.35	1.3×10^{-5}	2.5×10^{-4}
Crabs	0.01	0.24	2.7×10^{-6}	5.3×10^{-5}
Cumulative Risk******	**0.24**	**3.41**	$\mathbf{1.3 \times 10^{-4}}$**‡**	$\mathbf{1.1 \times 10^{-3}}$**‡¤**

* Multiple chemical exposures via single category of seafood. Explanation of average and high consumption rate consumptions is given in text.

** All trace metals except arsenic were evaluated.

*** Carcinogenic chemicals evaluated were arsenic, PAHs, BHC, chlordane, dieldrin, DDT and its derivatives, and total PCBs.

**** Multiple chemical exposure via multiple categories of seafood for the chemicals measured in this study. Any risk from tetrachlorodibenzo-p-dioxins should be added to these values to give a total cumulative risk.

‡ As part of a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990) a risk level of 1×10^{-4} was used as a benchmark and tissue risk values in excess of that level were flagged as possible problems.

¤ In a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990), EPA Region 6 recommended that if the 1×10^{-3} criterion was exceeded the State should consider issuing a fishing consumption ban.

Table 6.11. Risk characterization for the chemicals of concern measured in this study at Carancahua Reef in Galveston Bay.

	Non-Carcinogenic Risk Index Values**		Carcinogenic Risk Values***	
Seafood Category*	Average Consumption	High Consumption	Average Consumption	High Consumption
Fish	0.11	0.77	4.3×10^{-5}	3.3×10^{-4}
Oysters	0.17	3.31	2.5×10^{-5}	4.8×10^{-4}
Crabs	0.03	0.50	6.5×10^{-6}	1.3×10^{-4}
Cumulative Risk****	**0.24**	**4.58**	$\mathbf{7.4 \times 10^{-5}}$	$\mathbf{9.4 \times 10^{-4}}$‡¤

* Multiple chemical exposures via single category of seafood. Explanation of average and high consumption rate consumptions is given in text.

** All trace metals except arsenic were evaluated.

*** Carcinogenic chemicals evaluated were arsenic, PAHs, BHC, chlordane, dieldrin, DDT and its derivatives, and total PCBs.

**** Multiple chemical exposure via multiple categories of seafood for the chemicals measured in this study. Any risk from tetrachlorodibenzo-p-dioxins should be added to these values to give a total cumulative risk.

‡ As part of a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990) a risk level of 1×10^{-4} was used as a benchmark and tissue risk values in excess of that level were flagged as possible problems.

¤ In a dioxin tissue study conducted by EPA Region 6 (Crocker and Young 1990), EPA Region 6 recommended that if the 1×10^{-3} criterion was exceeded the State should consider issuing a fishing consumption ban.

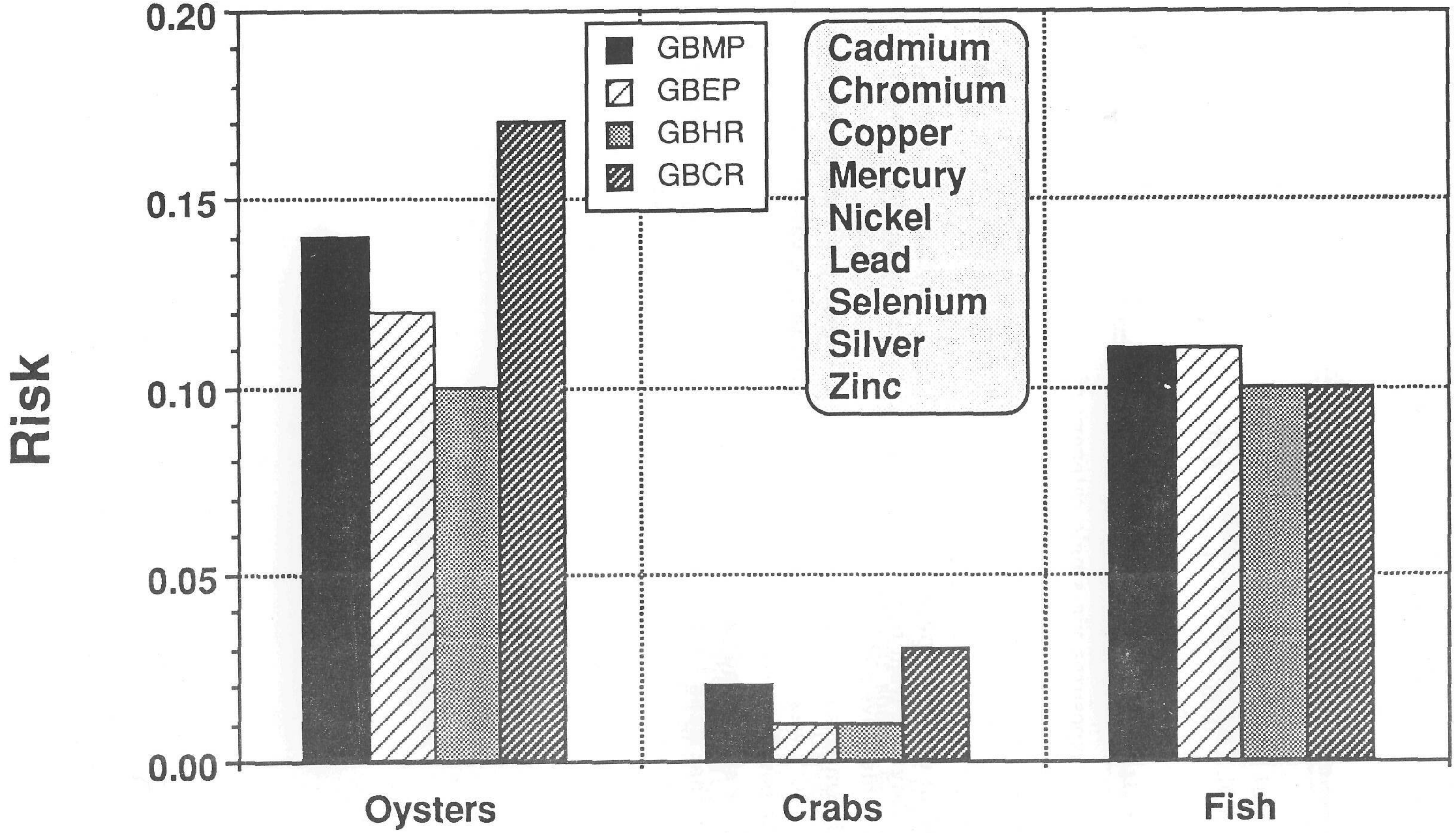

Figure 6.1. Non-carcinogenic risk values for an average consumer of Galveston Bay seafood.

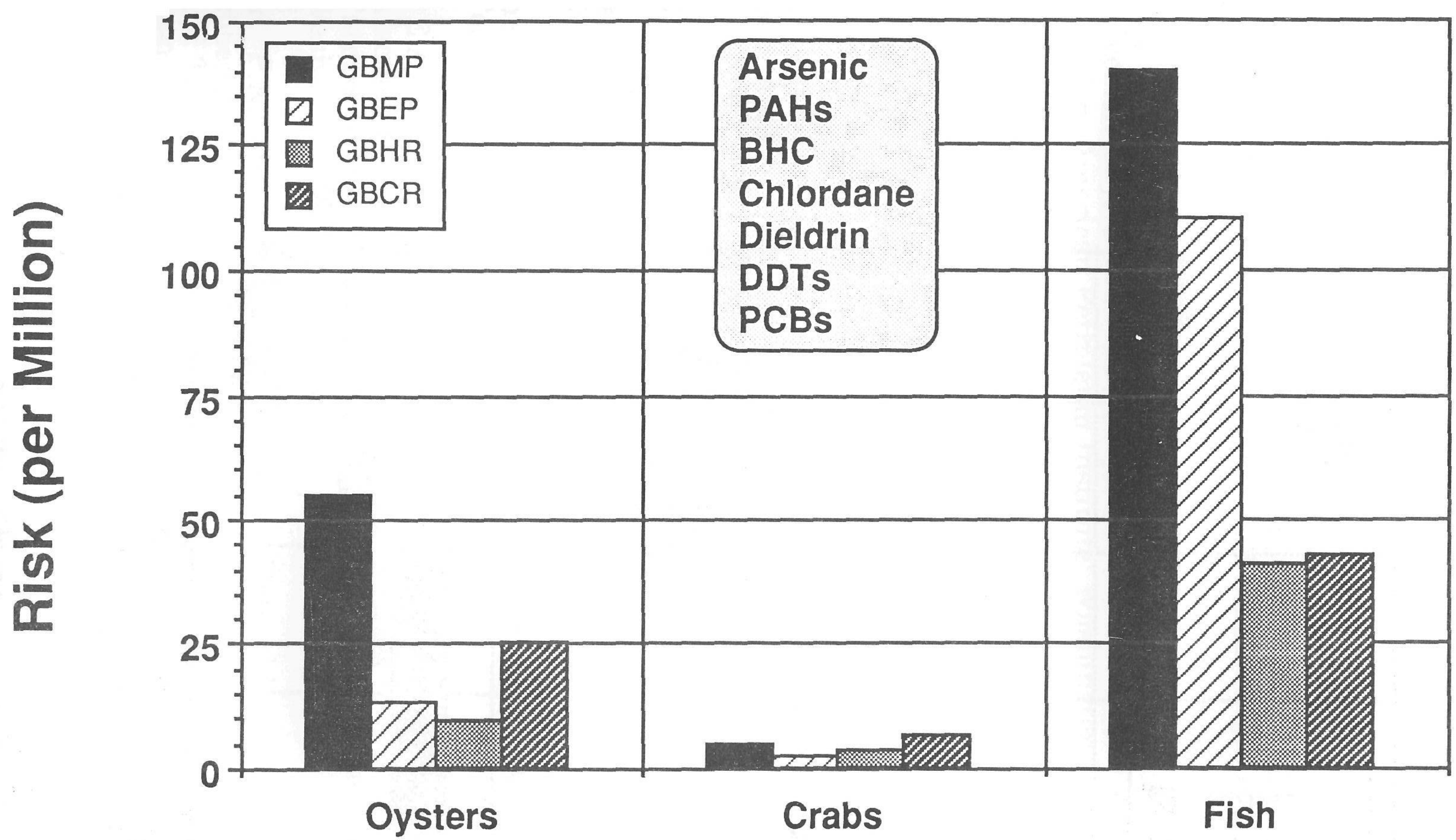

Figure 6.2 Carcinogenic risk values for an average consumer of Galveston Bay seafood.

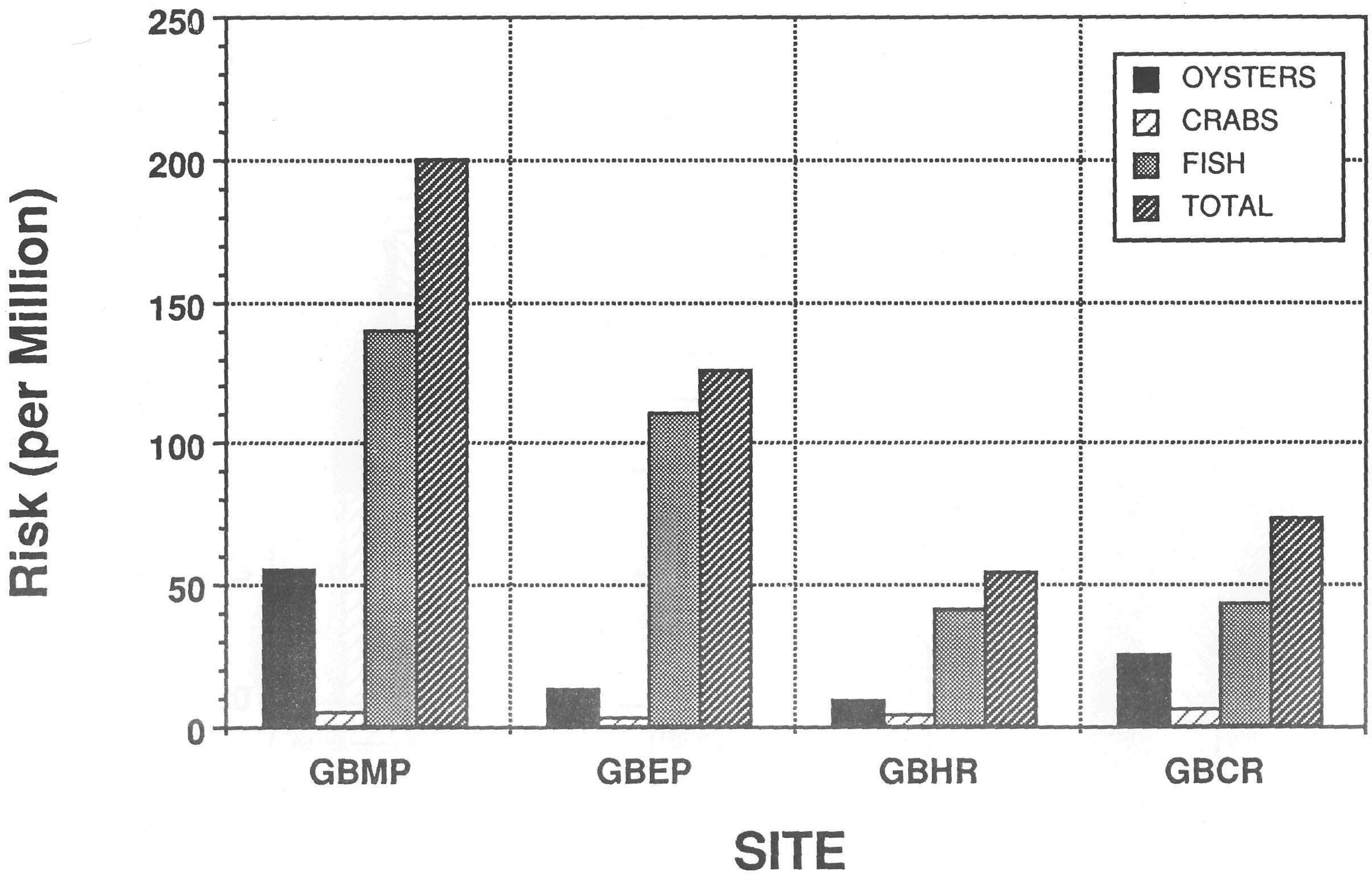

Figure 6.3. Lifetime carcinogenic risk by site for an average (15 g/d) consumer of Galveston Bay seafood.